MEMS Automotive Collision Avoidance Radar beamformer

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Overview

Introduction

- Rotman lens works by summing or focusing *N* in-phase samples of a wavefront at a focal point.
- It can be considered to be a true time-delay multiple beamformer.

- Currentlly used Rotman lens types
  _ Parallel plates (wave guide feed lines)
  _ Microstrip lens (stripline microwave printed circuit techniques to construct the feed section).

- For use in automotive collision avoidance systems
  - Position/Proximity sensors
  - Blind spot Measurements
  - Parking aid
  - Reverse aid
  - Pre crash
  - Stop/go sensor

State-of-the-Art

- The most common Rotman lens used in automotive collision detection are microstrip lens.
- Microstrip Rotman lens used in the industry have the following specifications:

Parameter	Value
Operating Frequency	77 GHz
Operating Range	100 m
Voltage	60 V
Size	5 to 10 cm
Gain of Main lobe	> 25 db
Side lobe	< -15 db
Beam width	4^0

State-of-the-Art

- Advantages of Rotman lens:

- Monolithic construction
- Ease of manufacture
- Low cost
- Light weight
- Simultaneous availability of many beams.
- Because it is a true time-delay device, the Rotman lens produces frequency-independent beam steering and is therefore capable of extremely wide-band operation.
- These features make the Rotman lens an attractive candidate for use in multibeam satellite-based applications.

Advantages of Rotman lens

- The Rotman lens is a true time-delay scanner that can be used either for receiving or transmitting.
- Increased range and detection performance over the ultrasonic sensors currently deployed as reverse parking aids.
- The design was improved by introducing a dielectric material in the parallel plate section (constant ε_r) reducing the dimensions of this section by $1/\sqrt{\varepsilon_r}$
- This improvement also permitted the use of microstrip and stripline microwave printed circuit techniques to construct the feed section.

Design Challenges

- Port spacing (it have to be in the range of the fractions of the wave length)
- Suppressing and reducing the sidelobes
- Reflections at the beam and array ports
- Isolation of individual beams and cross over levels

Port spacing

- Port spacing (it have to be in the range of the fractions of the wave length)
- The distance between ports can be minimized by using sidewall layers of a relative permitivity of one forth of the lens dielectric.
- Redirecting the port can reduce the port spacing

Reducing the sidelobes

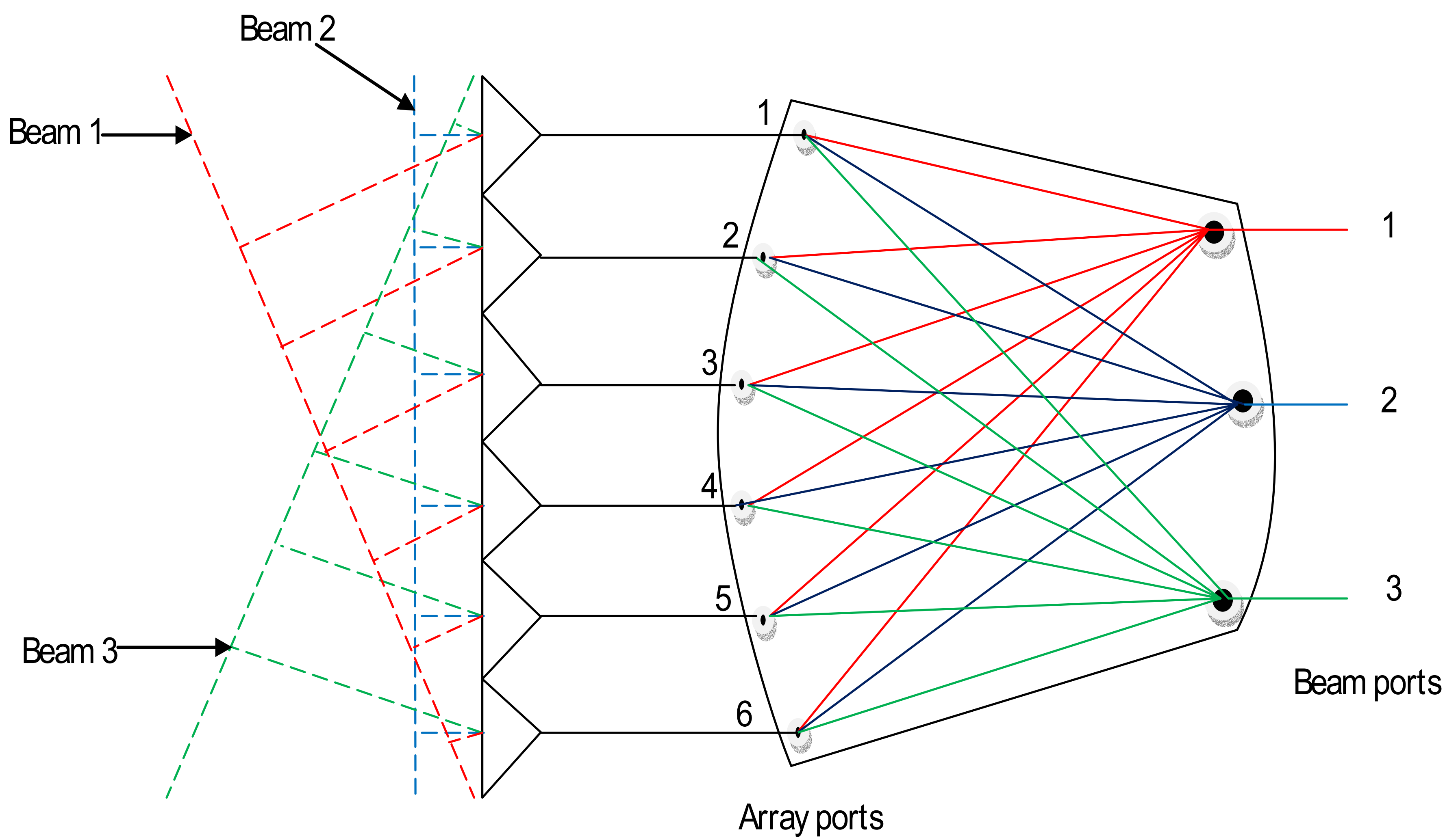
- Side lobe level improves (level of side lobe reduces with increase in element spacing).
- The sidelobe level of an array antenna fed by a Roman lens can be reduced if pairs of adjacent beam ports are combined.
- The system is fed through these summing ports.
- This procedure does not reduce the overall antenna gain.

Reflections at the beam and array ports

- Reflections at the beam and array ports can be reduced by introducing dummy ports that have matched resistance.

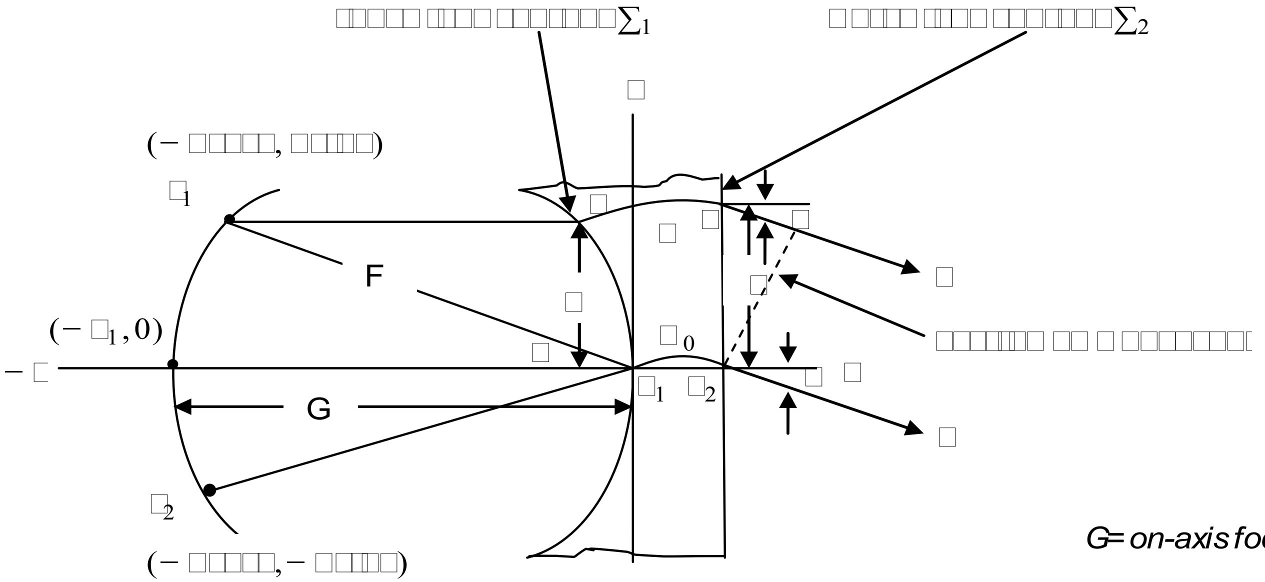
- Increasing element spacing, (but beam width decreases as element spacing increases).

Rotman Lens beamformer



Linear array fed by a Rotman lens

Rotman Lens parameters



(1)

(2)

(3)

G= on-axis focal length

F= off-axis focal length

W= electrical wire length

α= scanning angle

Rotman Lens Design Equations

$$\eta = {}^{N}/_{F}, \quad x = {}^{X}/_{F}, \quad y = {}^{Y}/_{F}, \quad w = \frac{W - W_0}{F}, \quad g = {}^{G}/_{F},$$

$$a_0 = \cos\alpha, \quad b_0 = sin\alpha$$

$$a = \left[1 - \eta^2 - \left(\frac{g-1}{g-a_0}\right)^2\right]$$

$$b = \left[2g\left(\frac{g-1}{g-a_0}\right) - \frac{(g-1)}{(g-a_0)^2} b_0^2 \eta^2 + 2\eta^2\right] - 2g$$

$$c = \left[\frac{g b_{0\eta^2}^2}{g-a_0} - \frac{b_0^4 \eta^4}{4(g-a_0)^2} - \eta^2\right]$$

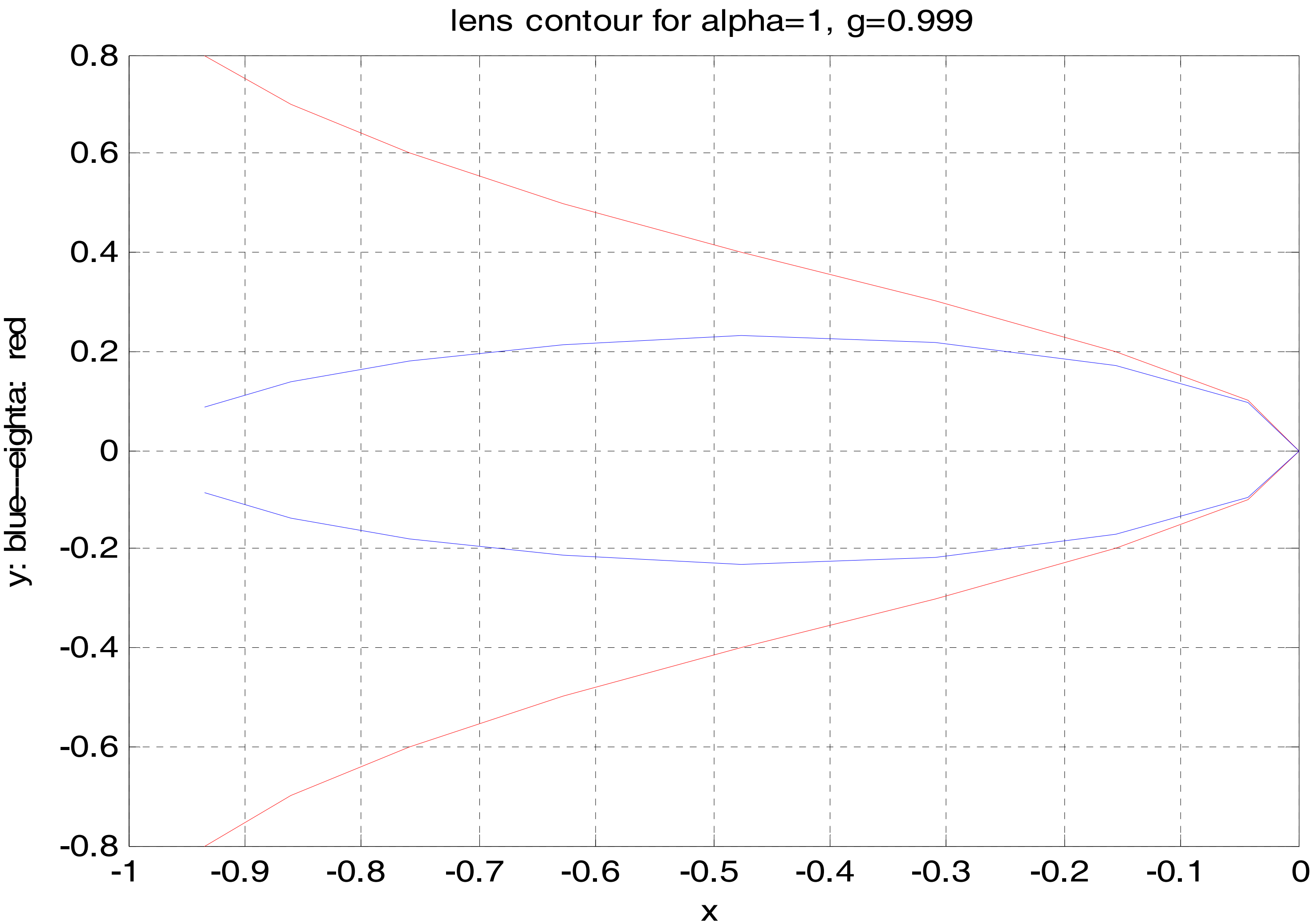
$$x = \frac{1-g}{g-a_0} w - \frac{b_0^2 \eta^2}{2(g-a_0)}$$

$$y = \eta(1-w)$$

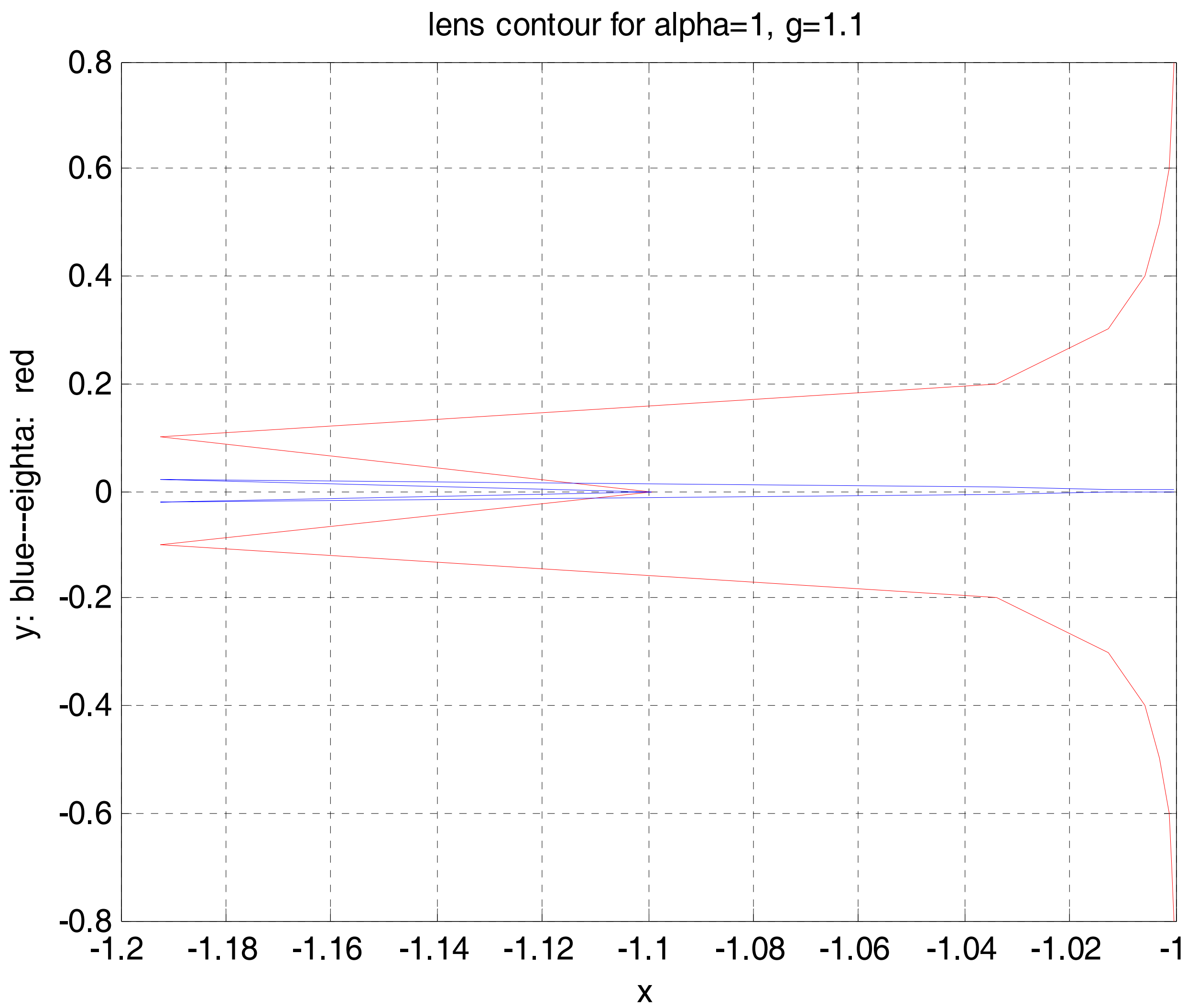
$$w = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

We use Matlab to obtain the lens contours for different values of (G) and (α) as shown below.

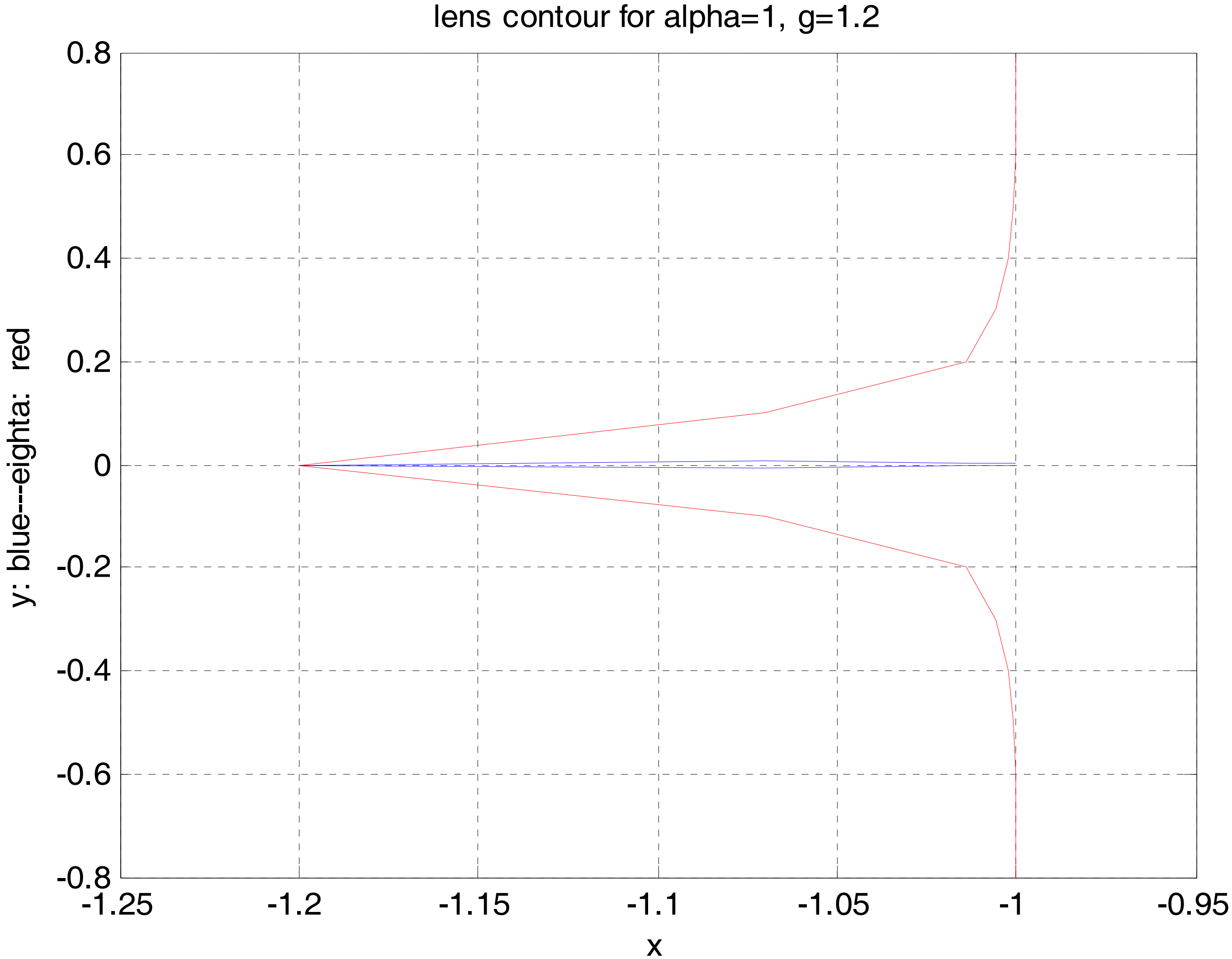
Lens contour for alpha=1, g=0.999



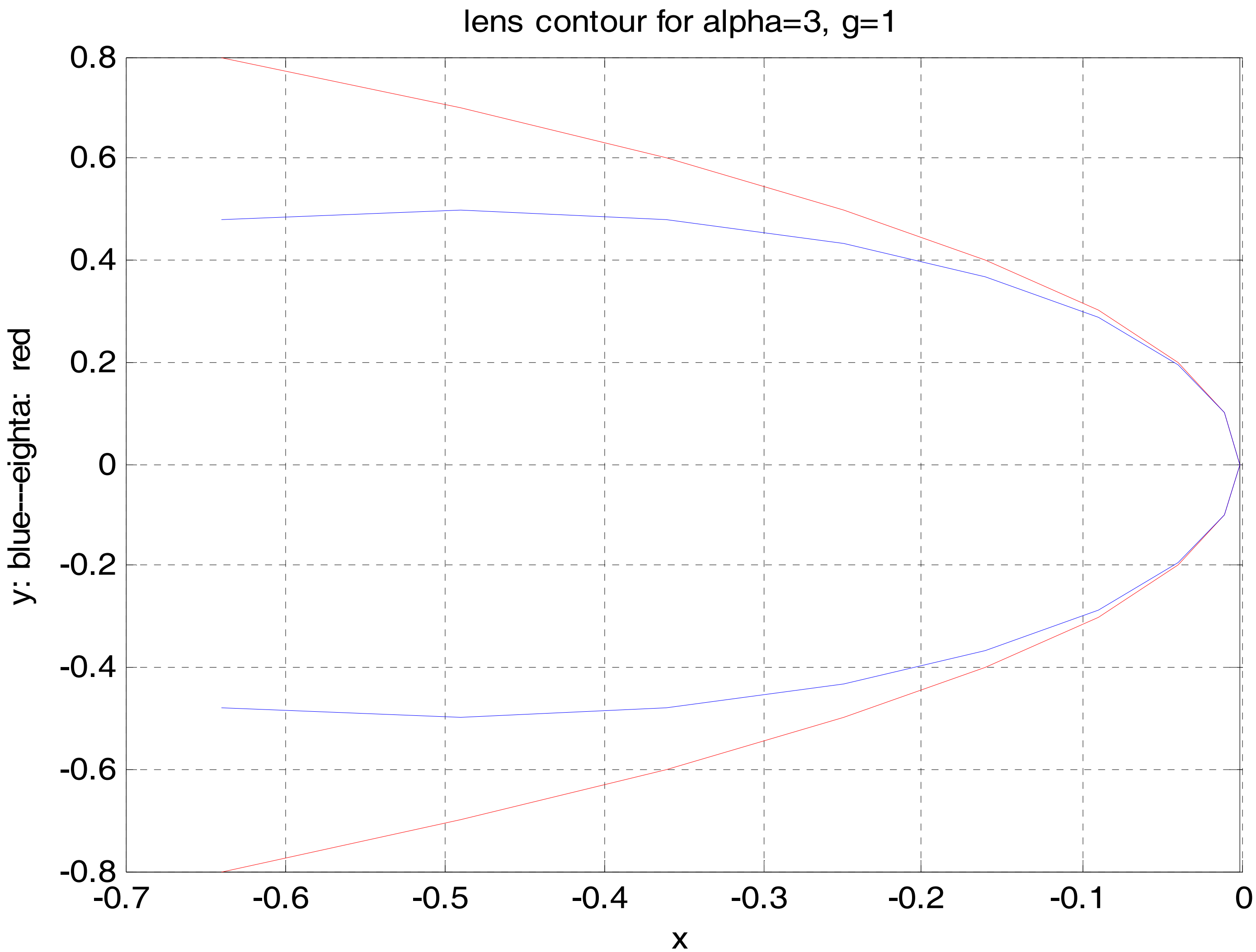
Lens contour for alpha=1, g=1.1



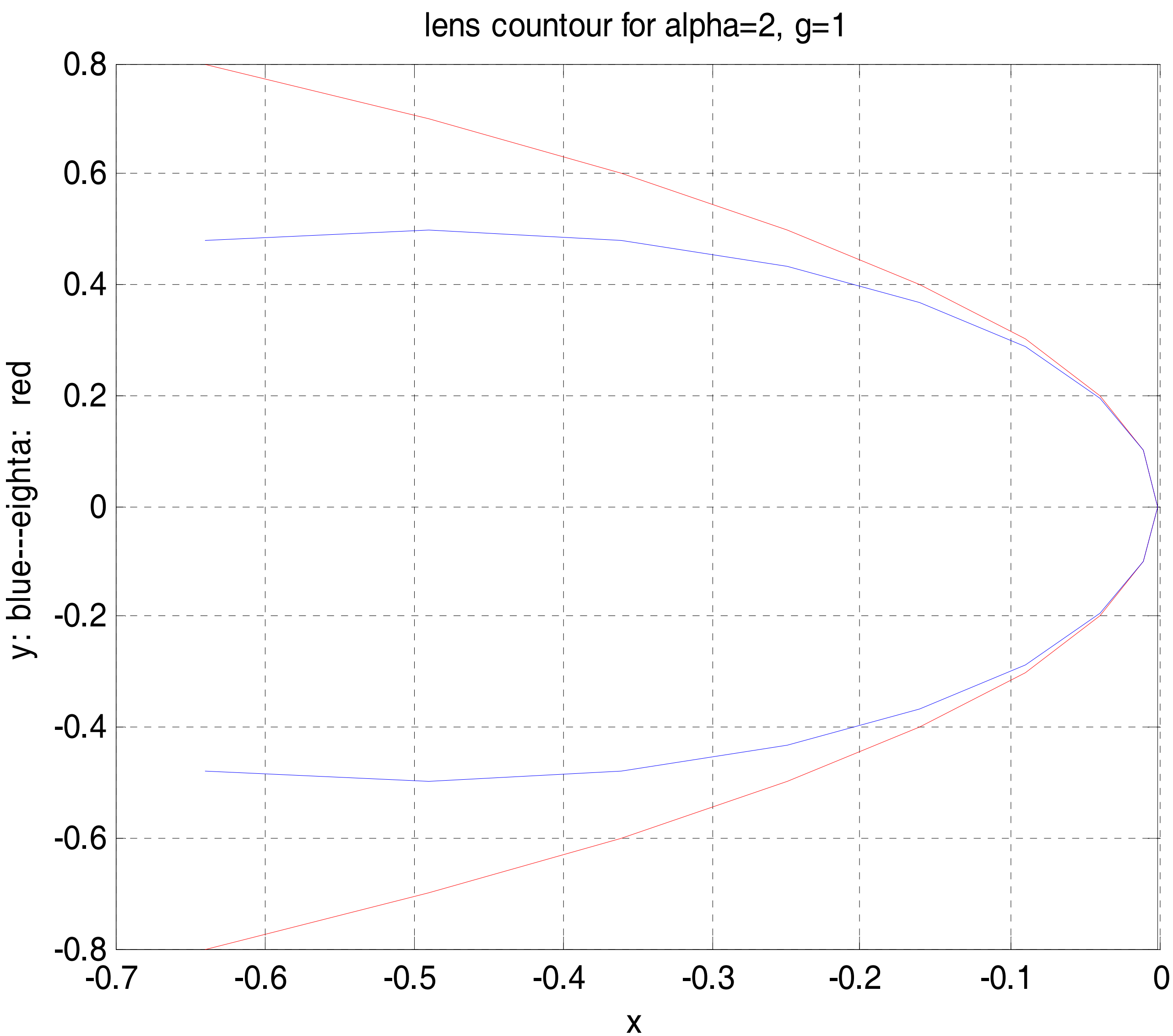
Lens contour for alpha=1, g=1.2



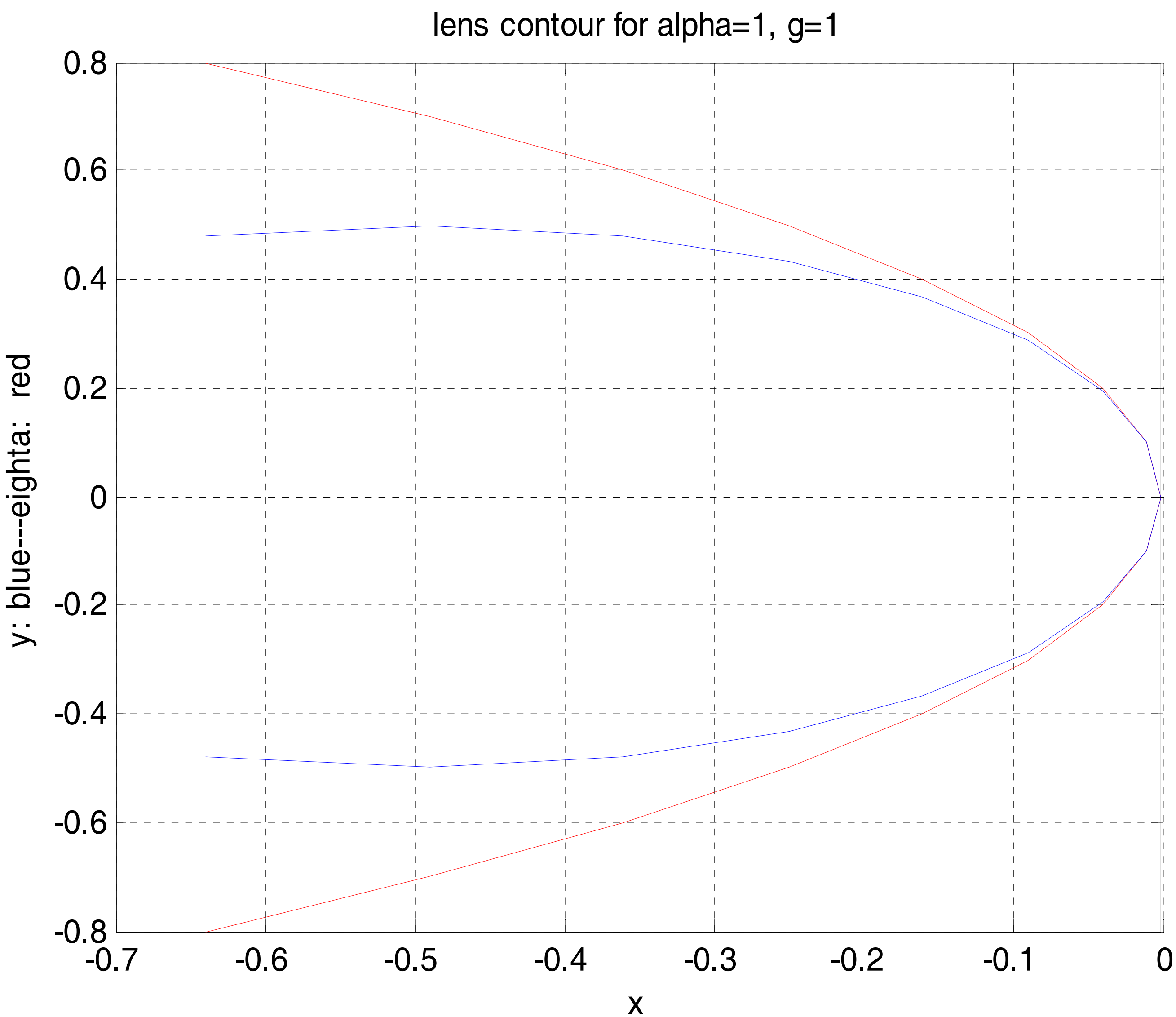
Lens contour for alpha=3, g=1



Lens contour for alpha=2, g=1



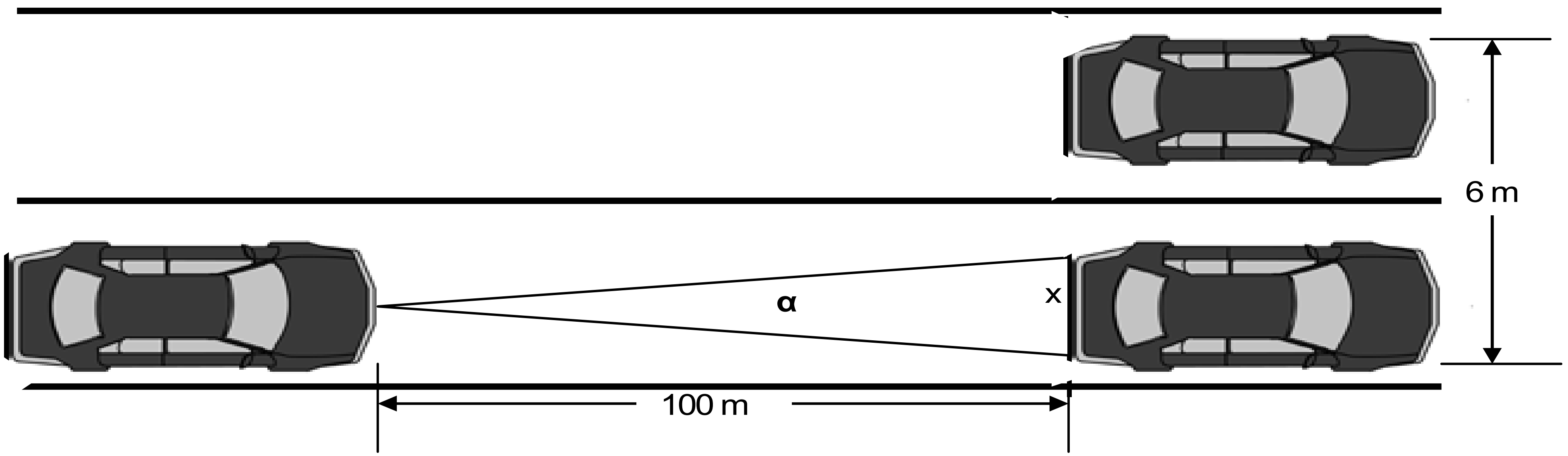
Lens contour for alpha=1, g=1



Why choosing g=1 and alpha=1

- The focal arc is centered at the vertex O_1 of the inner lens contour.
- The central ray paths from all points on the focal arc are equal in length.
- This setup of the lens is very important in monopulse applications.
- The shape of the lens will be approximated by a segment of a circle.
- The optical abberations are are very low.

Target scanning overview



If α=1 x=1.75 m

If α=2 x=3.50 m

If α=3 x=5.24 m

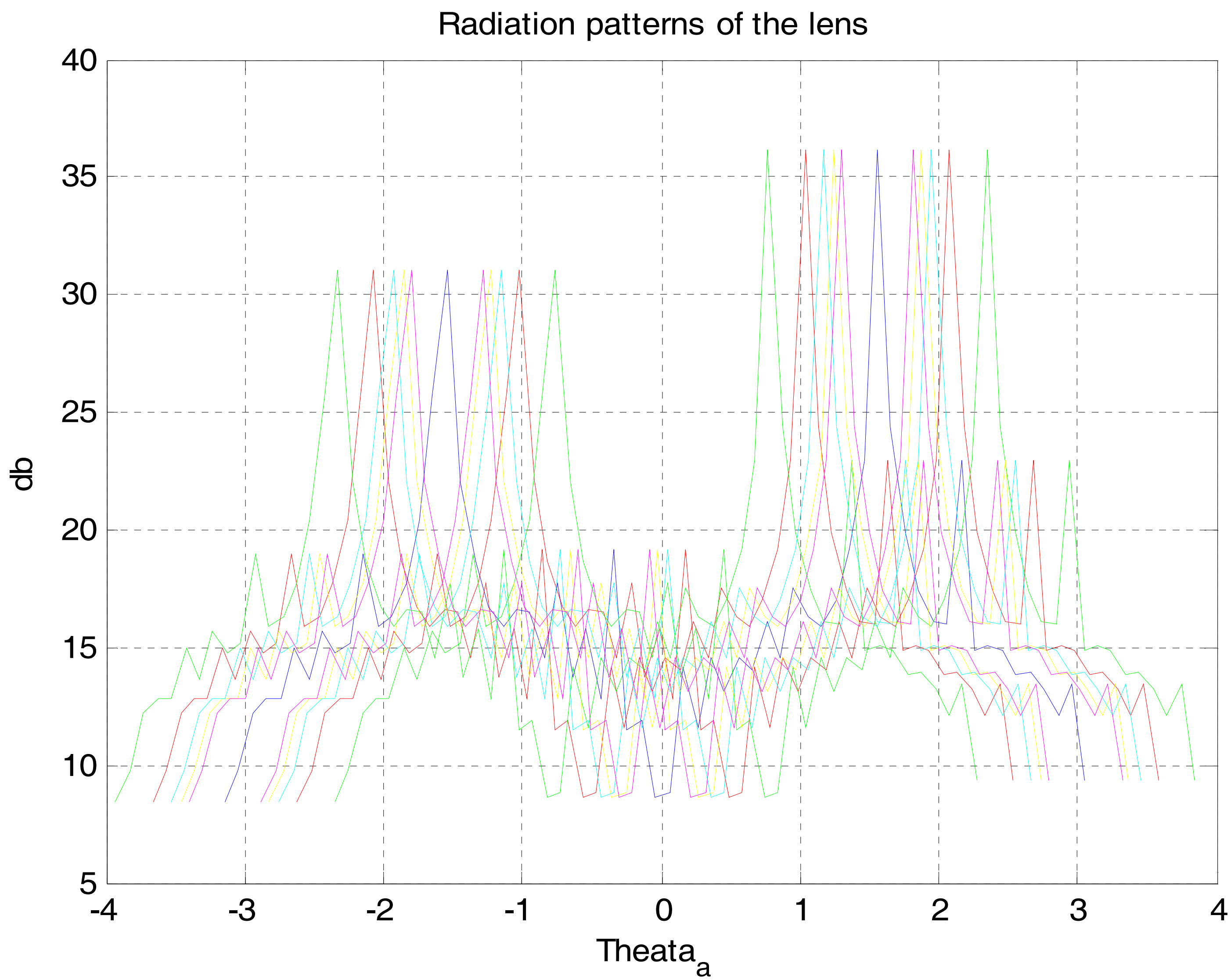
Rotman Lens

We obtain the optimal values for the parameters from our plots as follows:
X=-0.63995
Y=0.49994
W=1.6001
Eighta= 0.7
To find the radiation patterns of the lens, we have to plot gain of the lens versus the change of the array port angle.

$$\frac{P_r}{P_t} = \frac{l_a l_b}{\lambda} cos^2\theta_a cos^2\theta_b \left[\frac{\sin\,(\Pi l_a sin\theta_a/\lambda)}{\Pi l_a sin\theta_a/\lambda}\right]^2 \left[\frac{\sin\,(\Pi l_b sin\theta_b/\lambda)}{\Pi l_b sin\theta_b/\lambda}\right]^2$$

By taking the log of the equation above and plot it with the array angle, we got the following response.

Radiation patterns of the lens



Parameters calculation without insulation

we can define the length of the antenna array as

$$L_{1/2} = \frac{(N_a - 1)d}{2} = \frac{(N_a - 1)^{\lambda}/_{2}}{2} = \frac{(5-1)0.001945}{2}$$
$$= 3.89\ mm\ for\ N_a = 5$$

where

$L_{1/2}$ = half length of array,

N_a =the number of array elements, and

d = Spacing between antenna elements.

If we choose the maximum value of η the minimum value of scaling factor *F* can be obtained as

$$F_{min} = \frac{L_{1/2}}{\eta_{max}} = \frac{(N_a - 1)d}{2\eta_{max}} = \frac{0.00389}{0.7} = 0.00555\ m = 5.55\ mm$$

Parameters calculation without insulation

$$\eta = {}^{N}/_{F}, \qquad N = F\eta = 5.55 * 0.7 = 3.89\ mm$$

$$x = {}^{X}/_{F}, \qquad X = Fx = 5.55 * 0.63995 = 3.55\ mm$$

$$y = {}^{Y}/_{F}, \qquad Y = Fy = 5.55 * 0.49994 = 2.78\ mm$$

$$w = \frac{W - W_0}{F}, \qquad W - W_0 = Fw = 6.94 * 1.6001 = 8.89\ mm$$

$$g = {}^{G}/_{F}, \qquad G = Fg = 5.55 * 1 = 5.55\ mm$$

$$When \quad g = 1 \quad then \quad R = F = 5.55\ mm$$

$$The\ arc\ between\ F_1 \& F_2 = r\theta = 2 * \frac{\Pi}{180} * 5.55 * 10^{-3} = 0.1937\ mm$$

Parameters calculation with insulation

Using a high dielectric material $BaSrTiO_3$ (having a dielectric constant =6000), we can reduce the dimensions by a factor of $\sqrt{\varepsilon_r}$.

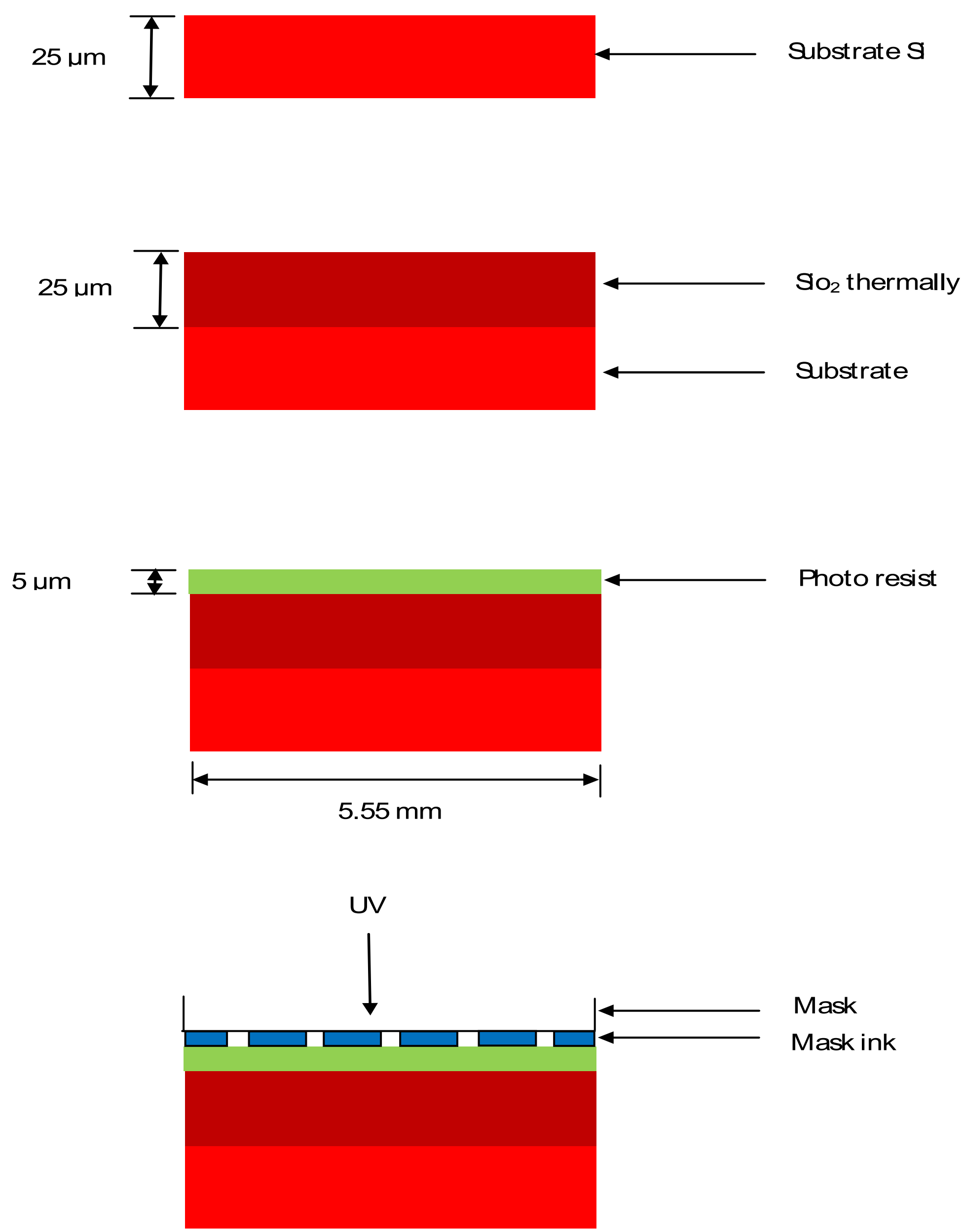
Paralell plate region height

$$< {}^{\lambda_m}/_2 \quad (\lambda_m = {}^{\lambda_0}/_{\sqrt{\varepsilon_r}}) = \frac{\frac{c}{f}}{\sqrt{\varepsilon_r}} = \frac{\frac{3\times10^8}{77\times10^9}}{\sqrt{6000}} = 50\ \mu m$$

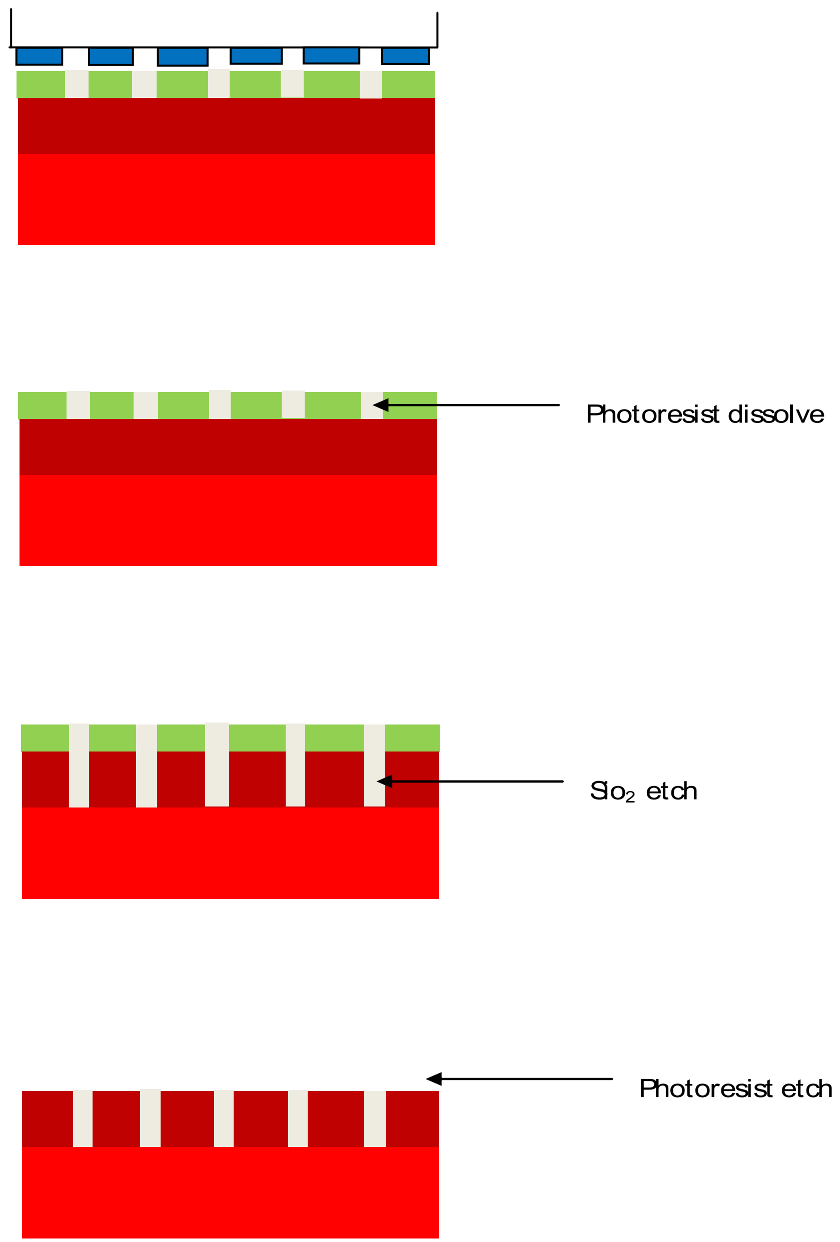
So the separation of the centres of the lens contours will be

$${}^{\lambda_m}/_2 = {}^{50}/_2 = 25\ \mu m$$

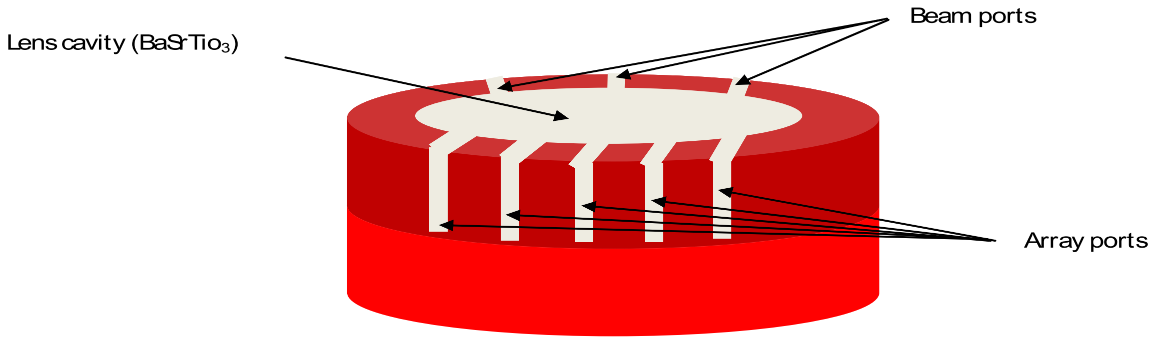
Fabrication process

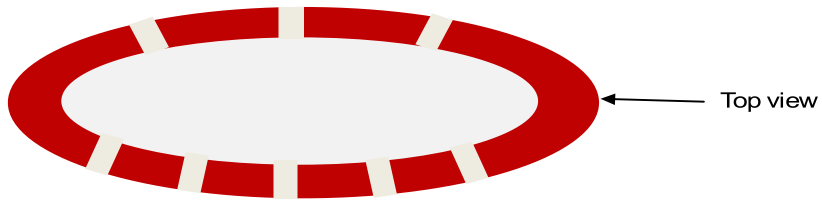


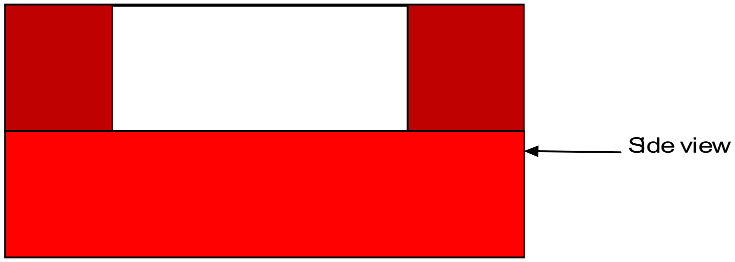
Fabrication process



Fabrication process

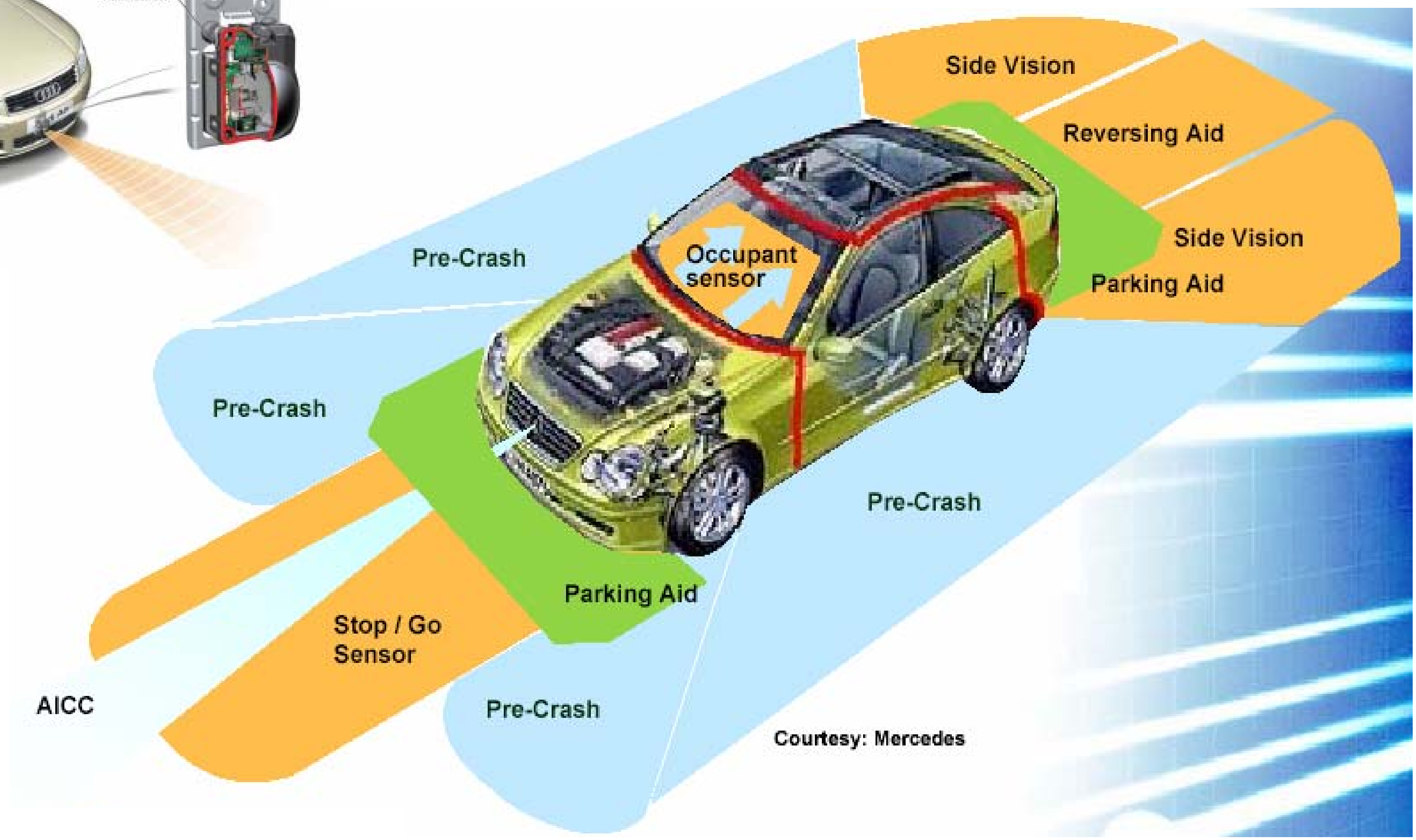






Target design specifications

Building a safety belt around the car



Courtesy: Cambridge Consultants

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